Machine Design and Modeling for Polishing X-Ray Mirror Elements

NASA Mirror Tech Days
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NASA SBIR/STTR Technologies

Proposal No. S2.05-8599 – Fabrication Technology for X-Ray Optics and Mandrels

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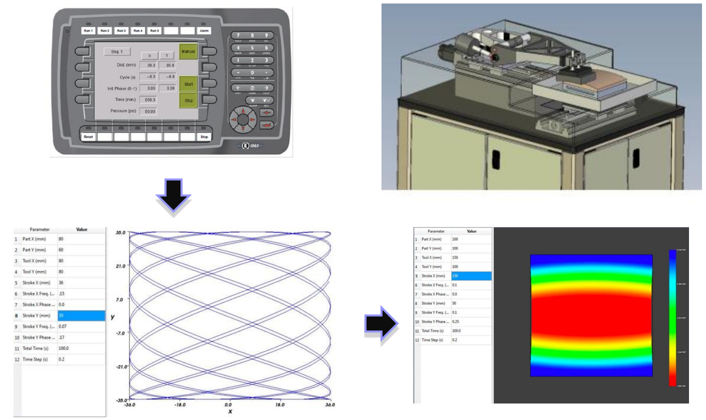
Identification and Significance of Innovation

Aperture Optical Sciences Inc. has built and commissioned a low-cost deterministic grinding and polishing machine for cylindrical optics. This machine may be modified for full scale production of X-Ray mandrels which exhibit the following benefits:
-Scalable to 1-meter scale optics
-Material independent (glass or SiC mandrels)
-Unlimited range of CX or CC radius of curvature
-Automated, programmable, with predictive control software
-Can be modified for flats and general aspheres

Expected TRL Range at the end of Contract (1-9): 2-3



Technical Objectives

1. Scale up existing design for full-scale mandrel production
2. Demonstrate algorithmic predictor model to produce aspheric shapes
3. Optimization of control system for low Mid-Spatial Frequency surfaces
4. Demonstrate the principal of sequential and superimposed removal patterning
5. Determine tolerance analysis for expected machine performance

Work Plan

1. Identify candidate upgrades necessary for existing machine
2. Develop and test the new model
3. Prepare feasibility study to demonstrate mandrel fabrication
4. Complete conceptual design review

NASA and Non-NASA Applications

IXO Replication Mandrels
GenX mandrels and optics
Precision Cylindrical Optics
Large Format Aspheres
Low Mid-Spatial Period Optical Surfaces
Deterministic Low Cost Fabrication

Firm Contacts

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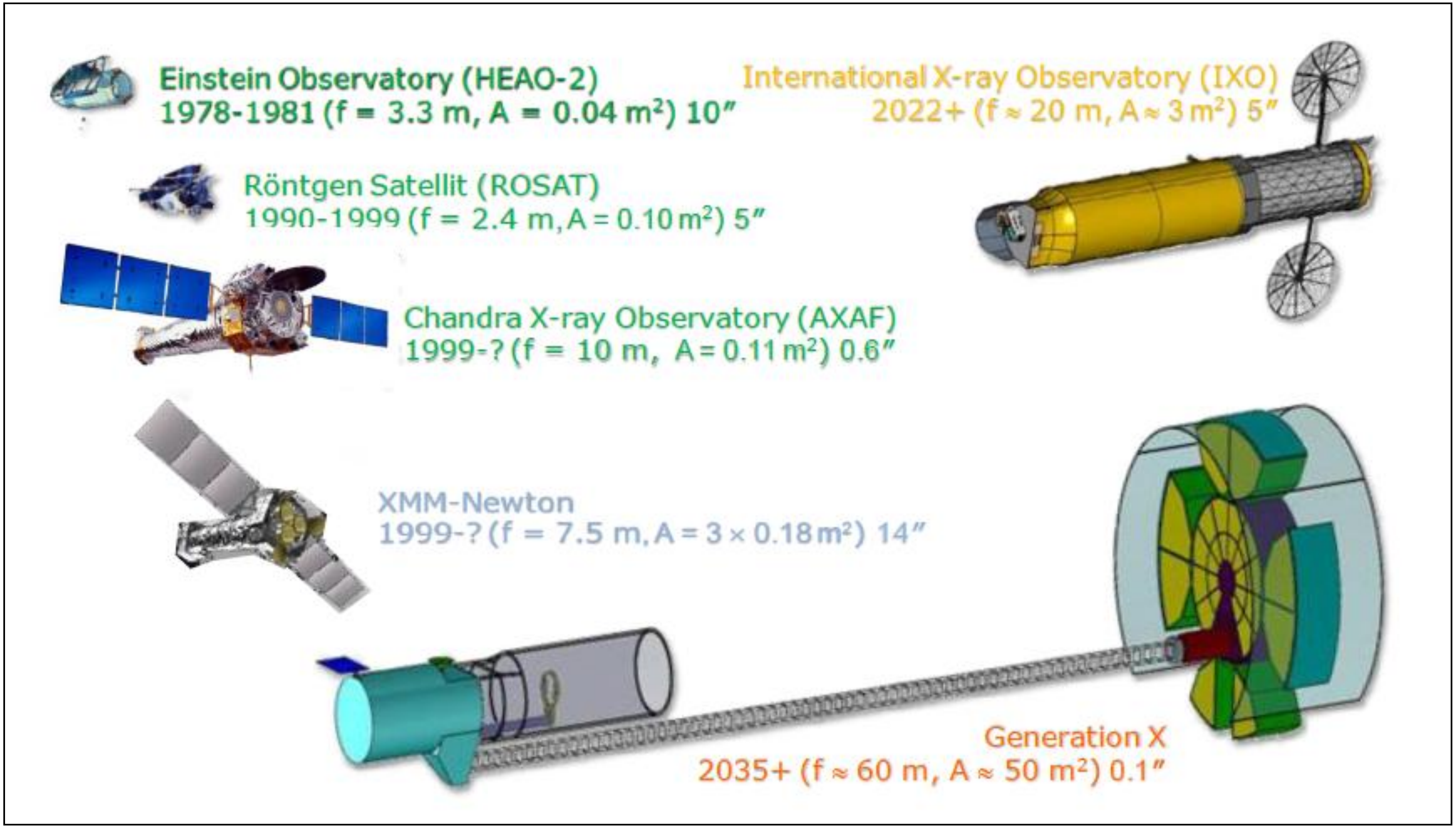
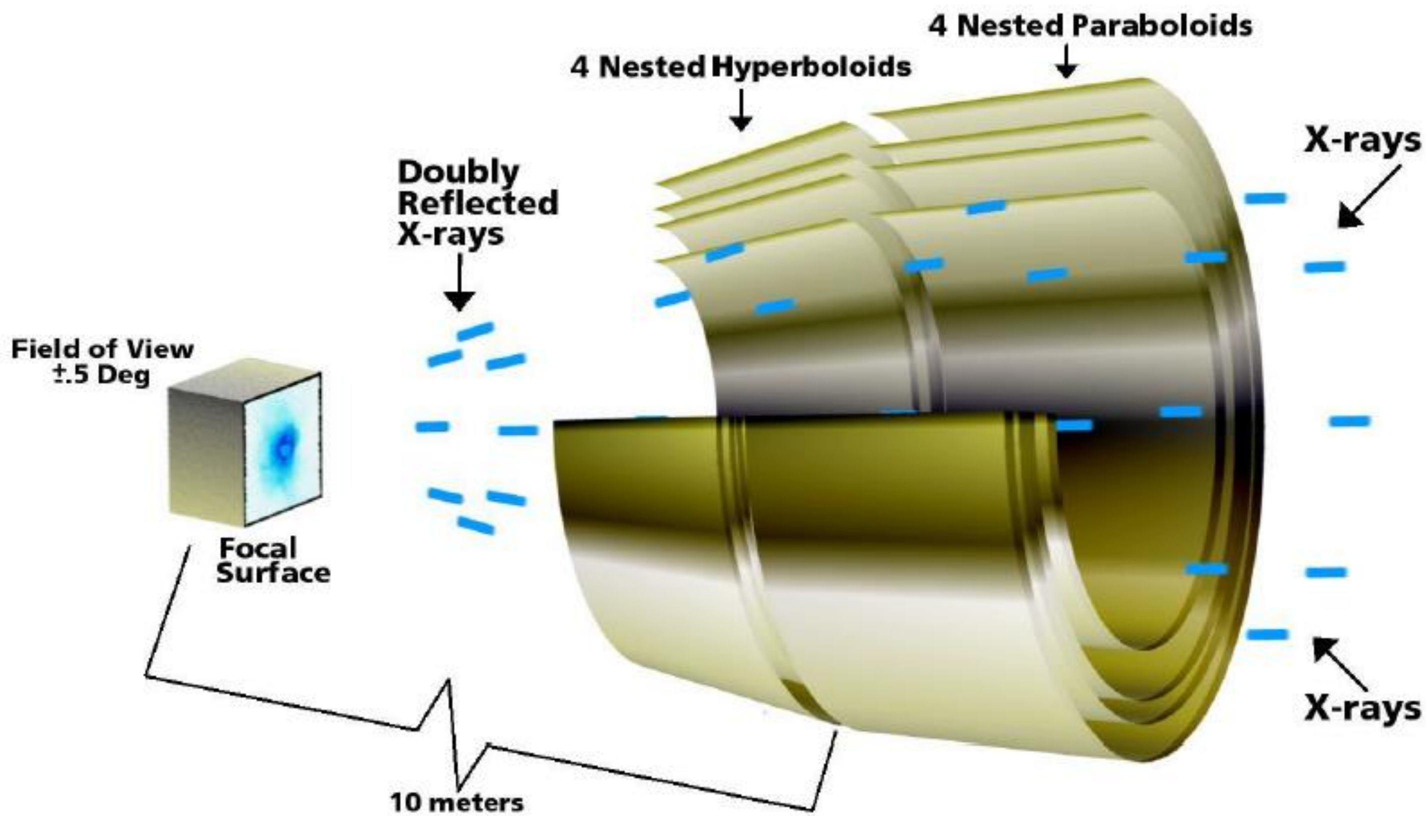
NON-PROPRIETARY DATA



f = focal length, A= effective collection area, and Half Power Density (HPD) in arc-sec.

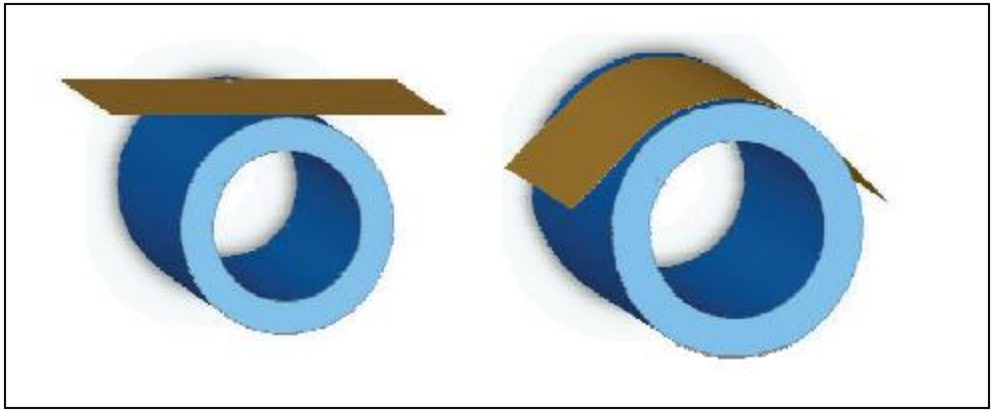
Example: Chandra X-Ray Observatory – Launched 1999



- Mirror elements are full shells 800 mm long and from 600 to 1200 mm in diameter, and were optically finished by ***computer controlled barrel polishing***.

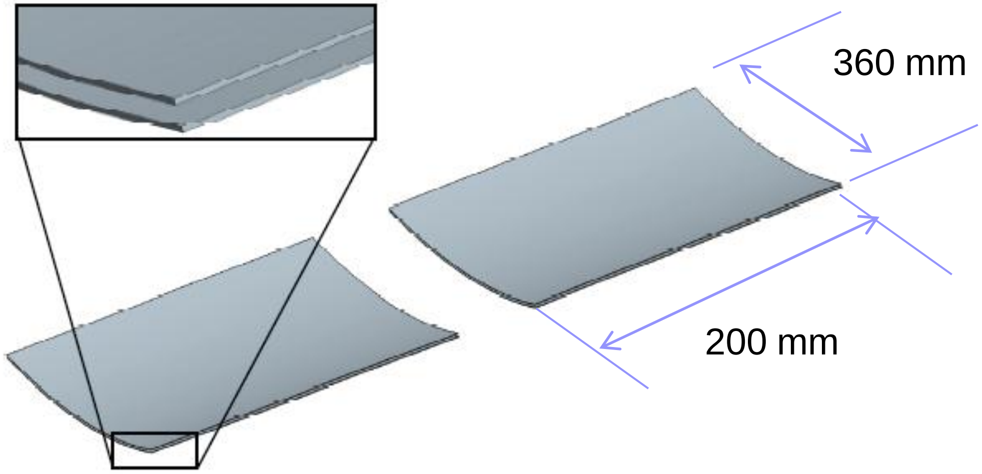
- Due to the high incident angles, surface specifications are dominated by slope errors rather than traditional surface specifications

Mirror Segment Slumping on Polished Mandrels

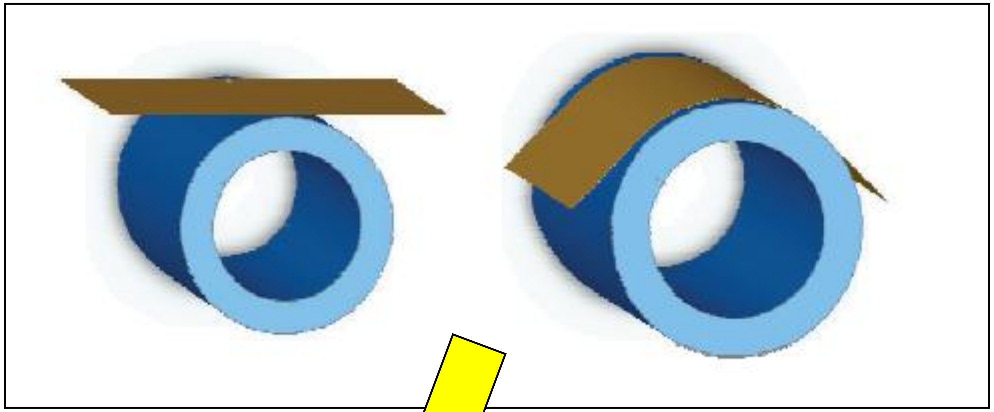


Mirror slumping process
•0.4 mm thick glass sheets
•Diamond turned and polished mandrels

Two pairs of primary (parabola) and secondary (hyperbola) mirror segments with 2mm spacing.



Mirror Segment Slumping on Polished Mandrels



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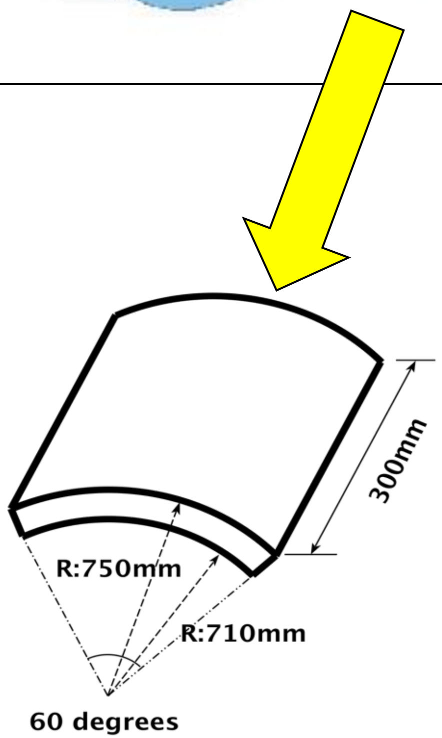
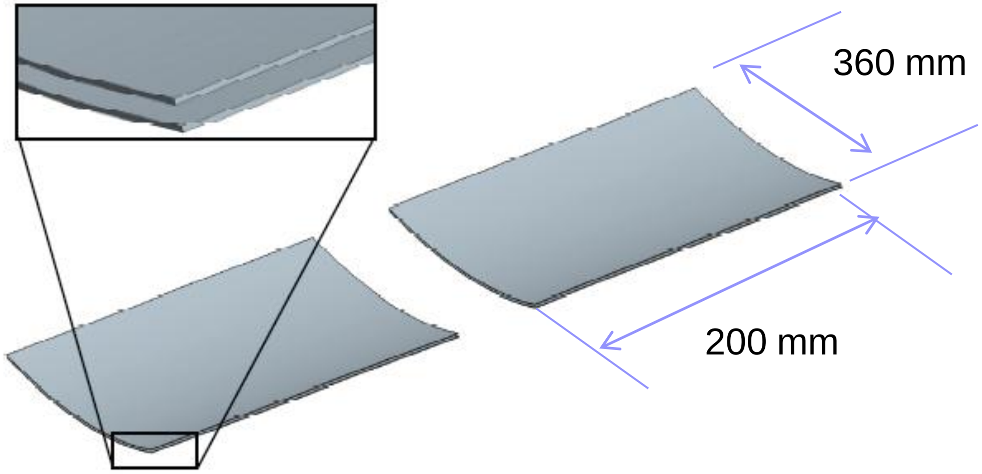
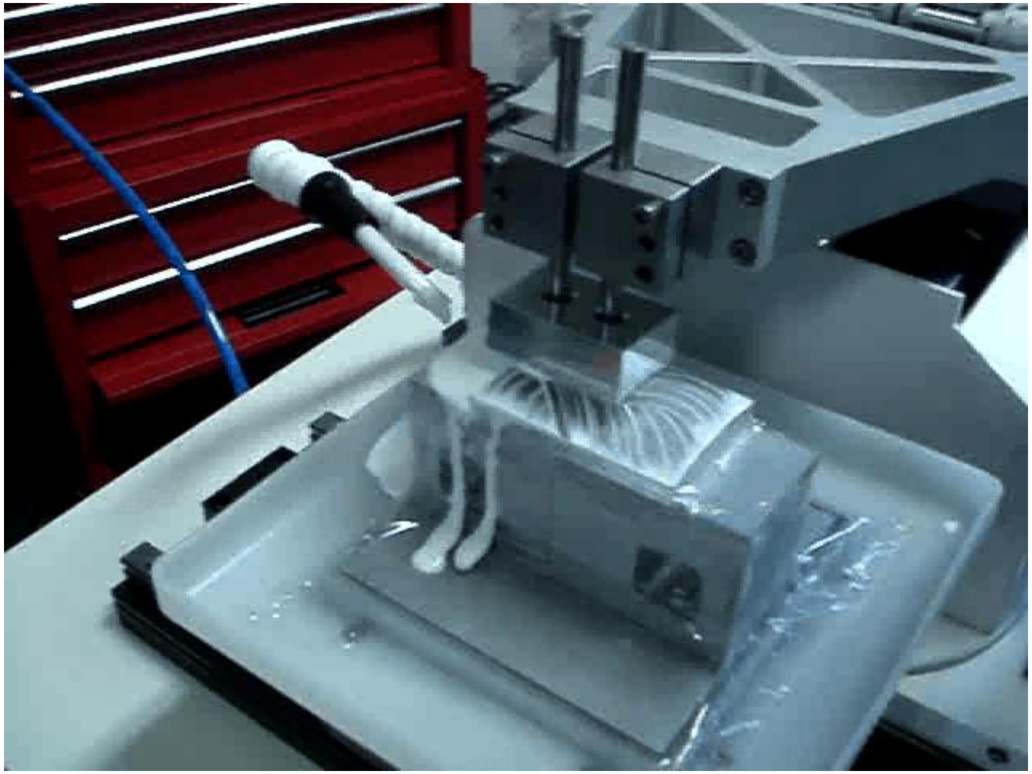




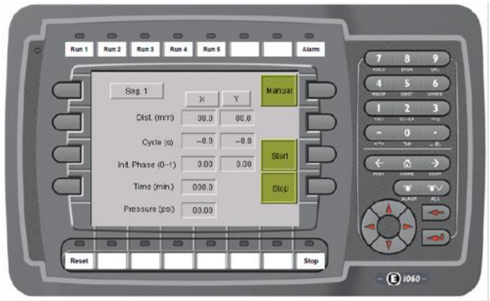
Mandrels for larger segments need only be partial rather than full shells – this allows us to consider alternative technologies to diamond turning & “barrel” polishing

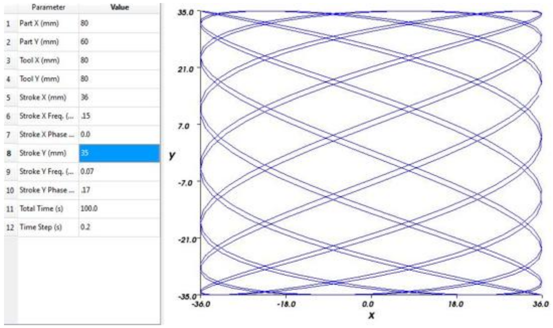
In 2009 AOS developed a computer controlled cylinder polisher

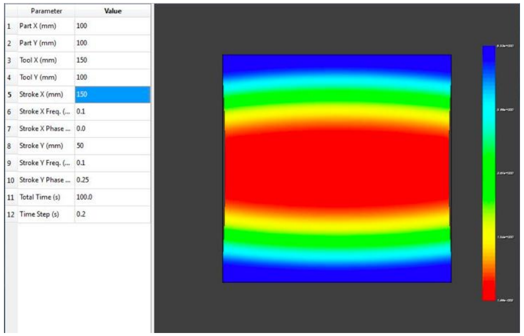


- The current SBIR was undertaken to investigate if this machine could be scaled up and modified for making conical and parabolic / hyperbolic segments cost effectively.

- The machine operation utilizes a large tool processing approach with a full-surface work function based algorithm. Machine motions, tool size and workpiece features are input to a work-function calculator that predicts the rate and geometry of material removal over the full surface of the workpiece.







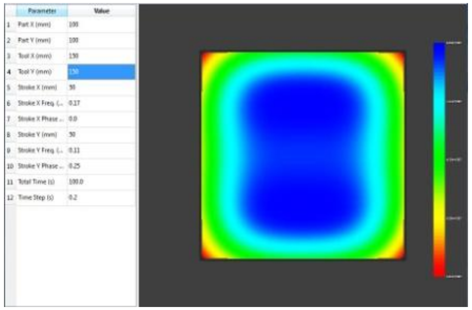
Workpiece feature and tool motion inputs

Tool path * time under controlled load

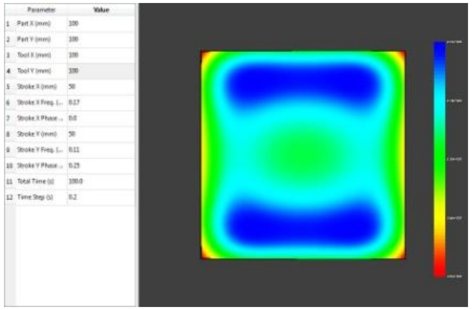
Full surface work function

Work Function Calculator based on tool size and path

- To illustrate the approach of large tool polishing we're creating a tool path calculator as part of a custom solver that demonstrates the impact of tool size and motion on the power spectrum of surfaces.



150%



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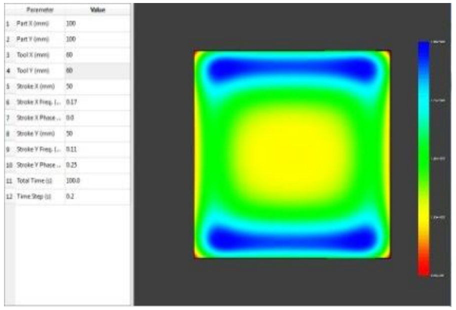
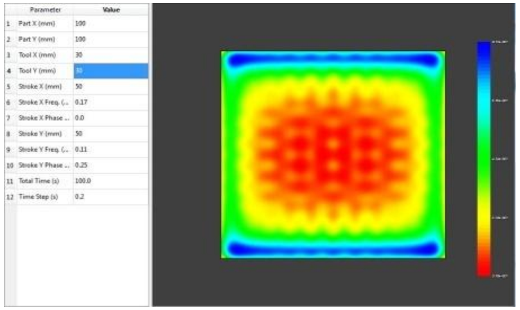


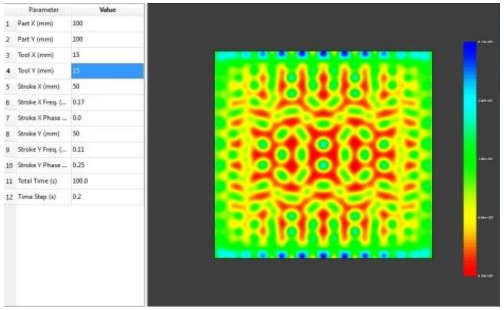
60%

Each photo shows the impact on tool to workpiece ratio:

$$\frac{\text{Area of Tool}}{\text{Area of Workpiece}}$$



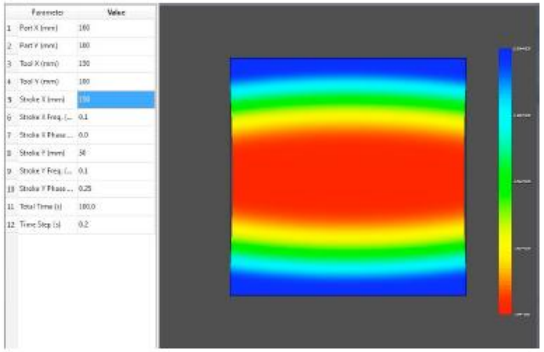
30%

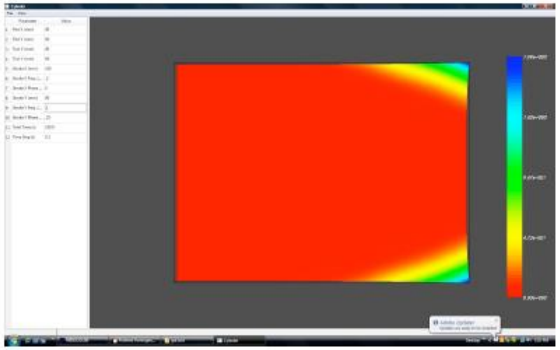


15%

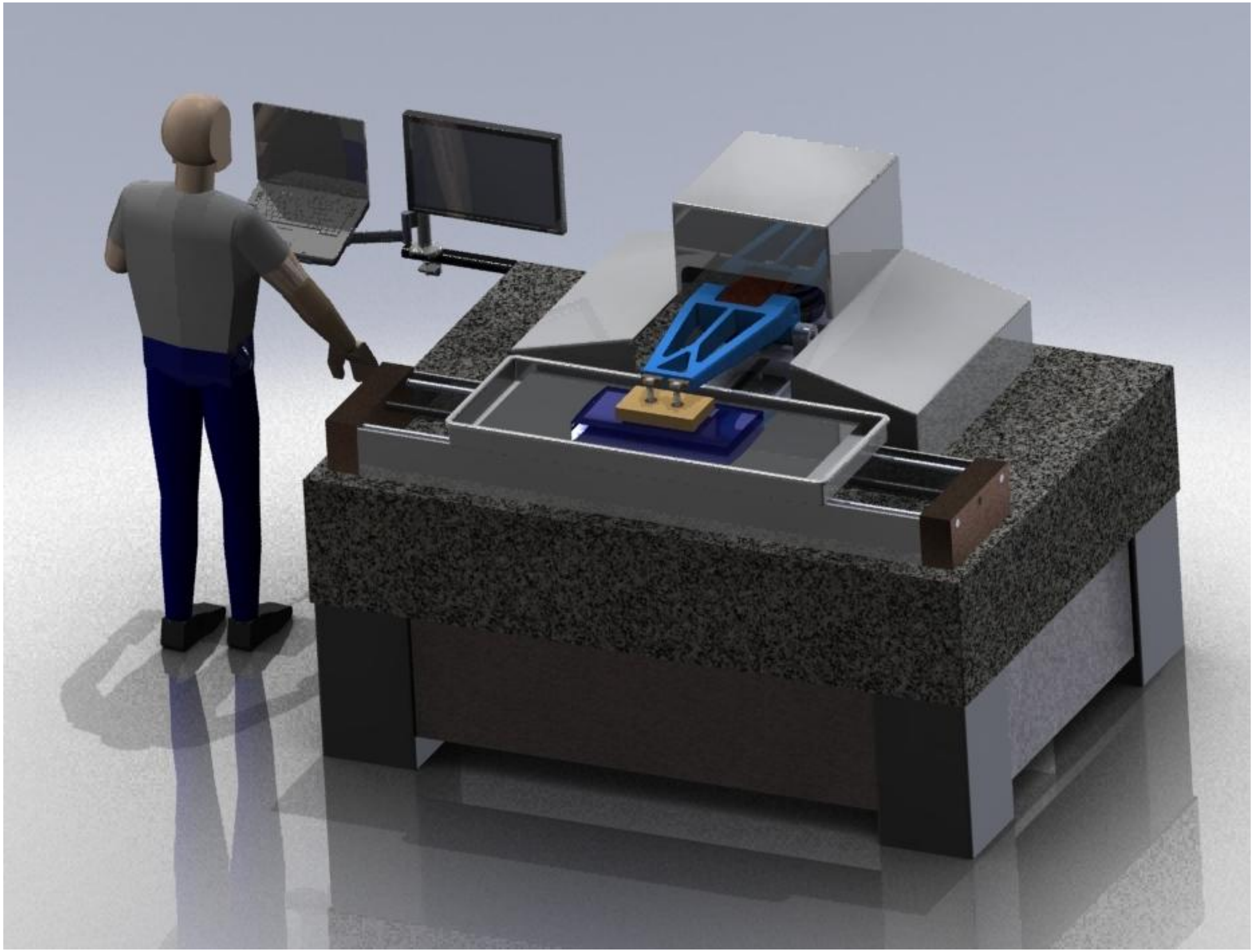
To adapt cylinder polishing to parabolic and hyperbolic "conical" segments, new features must be added

- Motions may be more complex, with variable accelerations, loads, and sequentially introduced combinations of machine settings. These require the development of a unique solver.
- The solver must first understand the nature of the desired form (e.g. the parabolic departure from a pure cone) plus whatever irregularities exist in the workpiece that require correction.

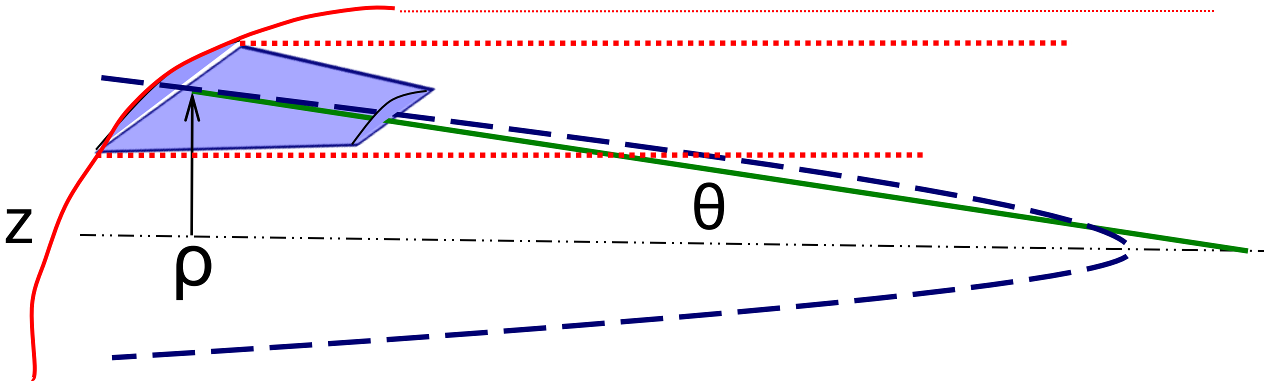




Early Concept of Large Tool Computer Controlled Polisher



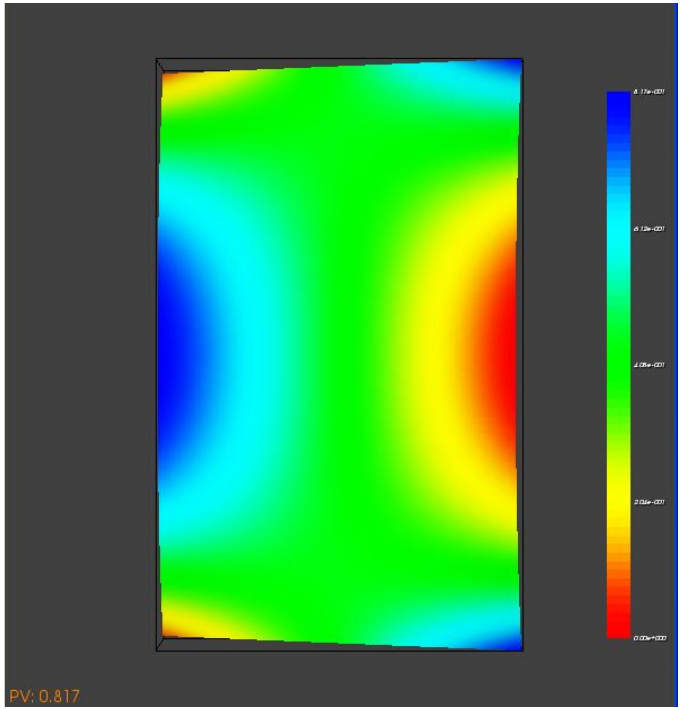
Solving for Parabolic and Hyperbolic conical segments



Required Design = Cylinder + Cone + Parabola / Hyperbola + Irregularity / Noise

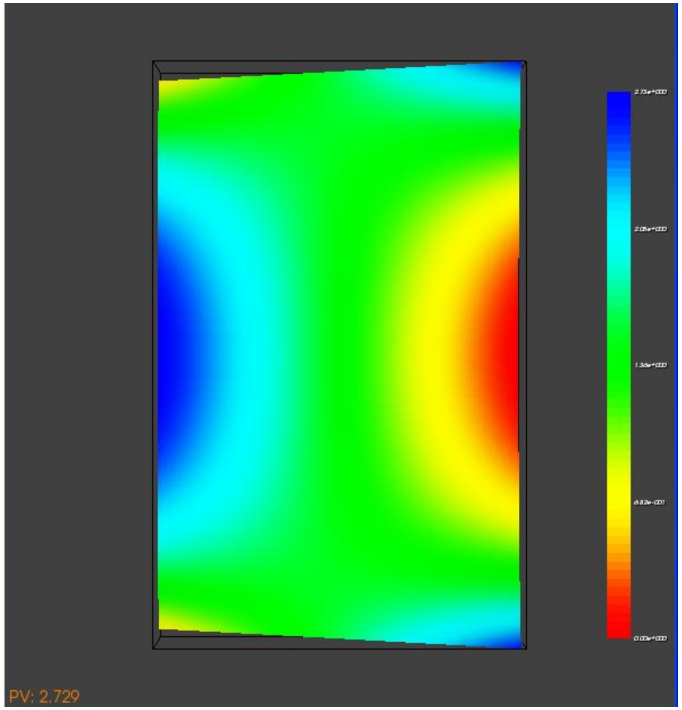
- Creating a machine solution and solver requires breaking the specification down into fundamental elements

- If we tilt the optics slightly, we can apply a "best fit cylinder" (BFC) to the optics segment. The departure from the cylindrical shape is asymmetric but relative small.
- The radius of the segment changes continuously from left to right.



Design - BFC for Parabolic Shape

Nodal Point: 10000mm
Axial Offset: 10031.9489631876mm
Parabolic Constant: 15.968117241298
Width 500mm
Cone Angle: 60 Degree

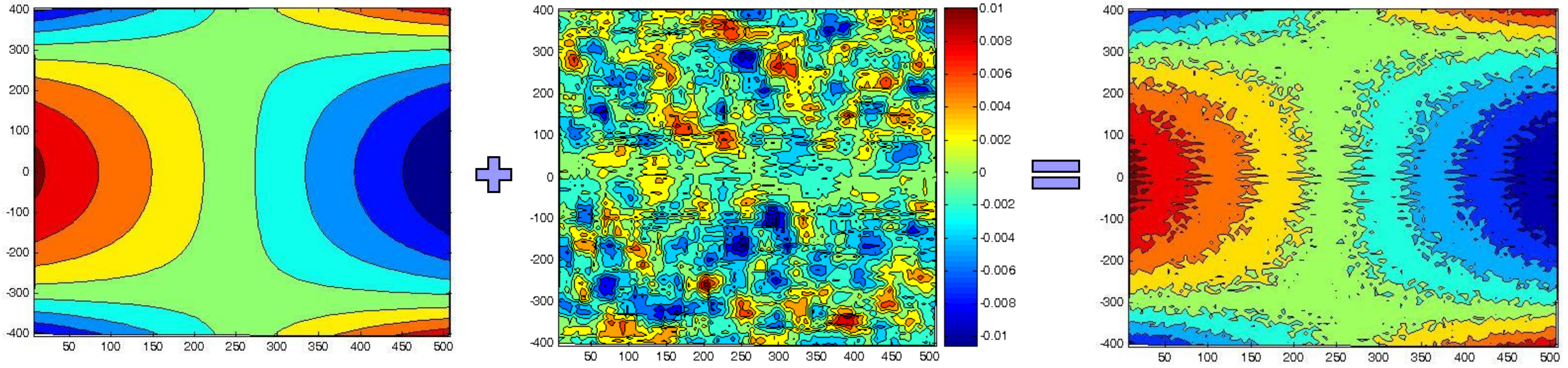


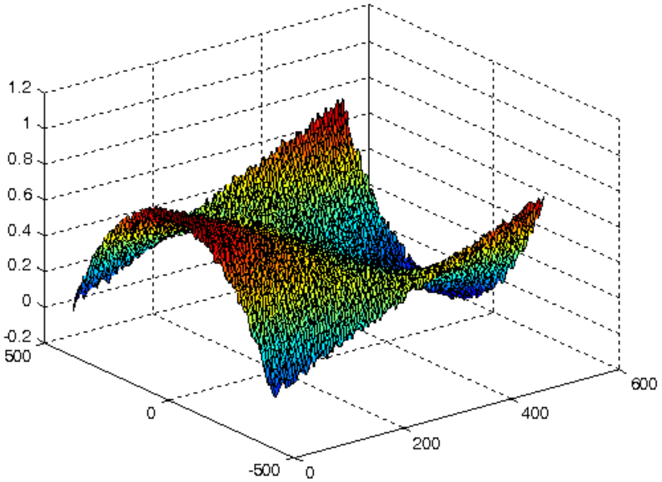
Design - BFC for Hyperbolic Shape

Nodal Point: 10000mm
Axial Offset: 10031.9489631876mm
Hyperbolic Constant: 1.001595536827
Width 500mm
Cone Angle: 60 Degree

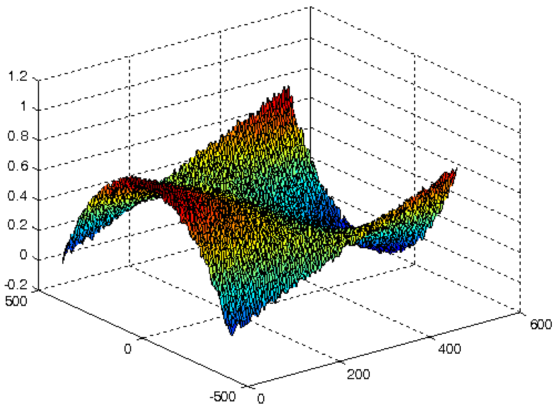
Development of the Large Tool Solver

- To simulate a real workpiece we add noise and local slope error to represent the an actual form.

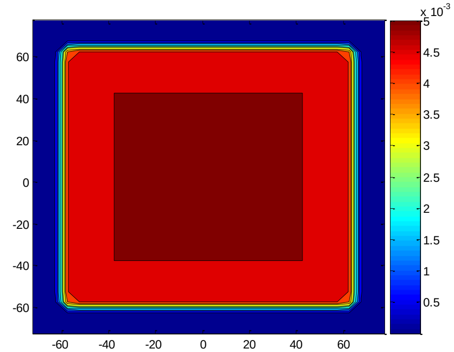




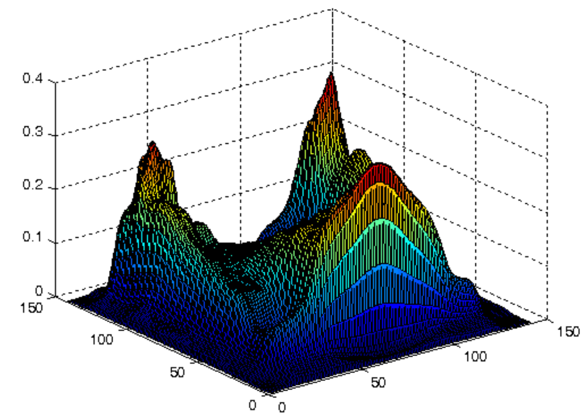
Simulation of the Solver



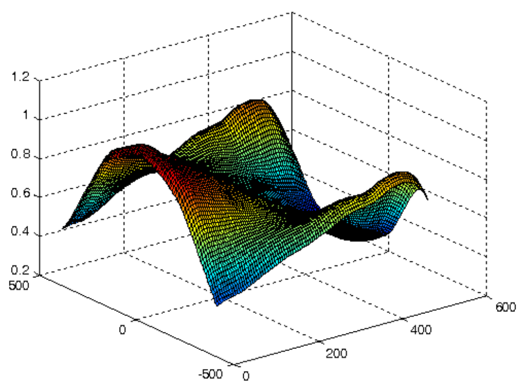
Target: This is the form we must impart to the cylinder with noise.



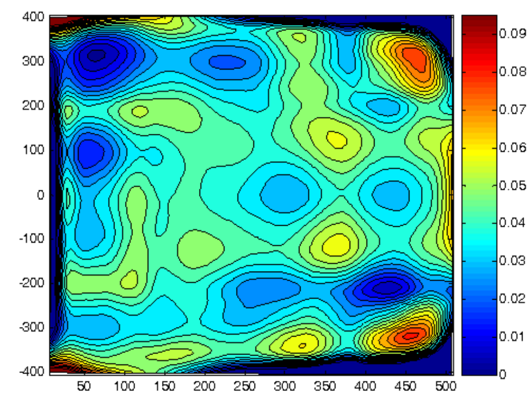
Removal function to be simulated, based on 30% tool to workpiece ratio. It can be measured spot.



Calculated dwell time



Calculated full surface removal

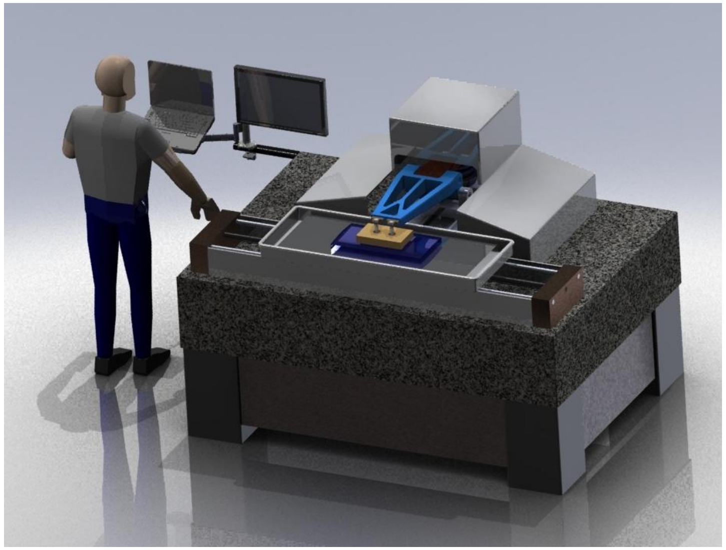


Error

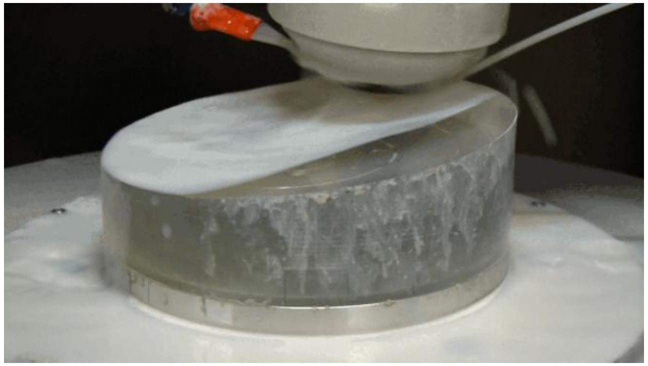
Where does Large Tool Processing fit in the Manufacturing Process?

Rough Generating

Large Tool Grinding & Polishing



Supplemental Finishing
(MRF, IBF, Robotic Polishing)



Remaining Tasks in our SBIR

- Complete development of the solver to run multiple simulations over typical x-ray mandrel segments
- Develop a working design of the machine that can execute the motions and dwell commands we are simulating